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(54) Symbol timing recovery in a multicarrier receiver

(57) An Orthogonal Frequency Division Multiplexing (OFDM) receiver that compensates for FFT window drift by extracting (50, 52) a training symbol from a fast Fourier transformed OFDM signal, and processing (60, 62, 66) the extracted training symbol to derive an FFT window adjustment factor and an associated equalizer tap initialization value. The OFDM receiver controls the position of an FFT window and the initialization of equalizer taps using the FFT adjustment factor and equalizer tap initialization value. The OFDM receiver preferably filters (56, 64) the fast Fourier transformed OFDM signal to remove additive channel noise and increase the likelihood of reliable equalizer tap initialization in a low SNR environment.

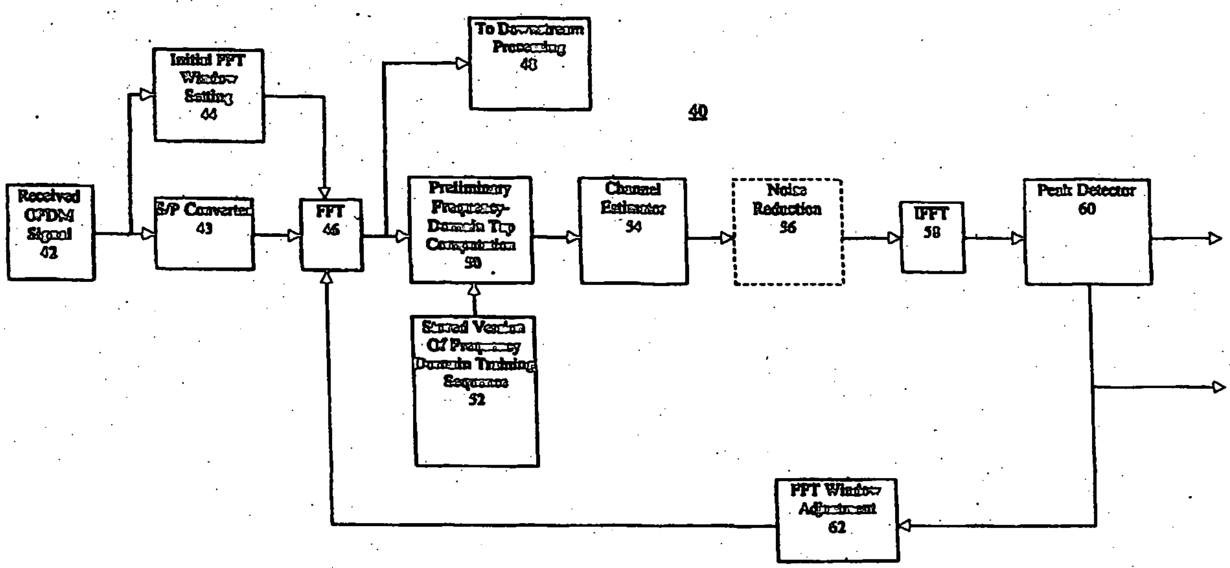

FIG. 4

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FIG. 7 is a graph comparing the phase of an actual channel frequency response with the phases of noisy and noise-reduced channel estimates; and

FIG. 8 is a block diagram illustrating a recursive filtering system for the window shift correction and equalizer tap initialization arrangement of the present invention.

[0010] The characteristics and advantages of the present invention will become more apparent from the following description, given by way of example.

[0011] Turning to FIG. 3, an exemplary OFDM symbol frame 30 of the present invention is shown. Symbol frame 30 includes a training sequence or symbol 32 containing known transmission values for each subcarrier in the OFDM carrier, and a predetermined number of cyclic prefix 34 and user data 36 pairs. For example, the proposed ETSI-BRAN HIPERLAN/2 (Europe) and IEEE 802.11a (USA) wireless LAN standards, herein incorporated by reference, assign 64 known values or subsymbols (i.e., 52 non-zero values and 12 zero values) to selected training symbols of a training sequence (e.g., "training symbol C" of the proposed ETSI standard and "long OFDM training symbol" of the proposed IEEE standard). User data 36 has a predetermined number of pilots 38, also containing known transmission values, embedded on predetermined subcarriers. For example, the proposed ETSI and IEEE standards have four pilots located at bins or subcarriers ± 7 and ± 21.

[0012] Referring now to FIGS. 4 and 5, an FFT window synchronization and equalizer tap initialization system 40 of the present invention is shown. It should be noted that system 40 may be embodied in software, hardware, or some combination thereof. For example, system 40 may be part of an WLAN adapter that is implemented as a PC card for a notebook or palmtop computer, as a card in a desktop computer, or integrated within a hand-held computer or a home networking terminal. System 40 is coupled to a source 42 of OFDM time-domain samples (e.g., the output of an ADC) that has a sampling frequency offset with respect to the sampling frequency of an OFDM transmitter. As noted above, such an offset could cause an FFT window drift which, in turn, may result in a phase rotation in the output of an FFT unit and ISI. System 40 includes an initial FFT window setting unit 44 coupled to source 42 and an FFT unit 46 coupled to source 42 via a serial to parallel converter 43. Initial FFT window setting unit 44 obtains an initial estimate of the FFT window position and triggers FFT unit 46 when the samples from source 42 fall within the estimated window position. Initial FFT window setting unit 44 may use known window synch techniques such as detection of cross-correlation peaks or autocorrelation peaks of a known training sequence (e.g., training sequence 32 of FIG. 3). Initial FFT window setting unit 44 obtains an approximate (within several samples of the correct window position) initial estimate of the window position. Afterwards, the window position is finely adjusted, as described in further detail below. It should be noted that the coarse FFT window position set by unit 44 is preferably within a known sample range from the correct FFT window setting.

[0013] The output of FFT unit 46 is passed to downstream processing units 48 and to a preliminary frequency-domain tap computation unit 50. Downstream processing units 48 include an equalizer (shown in FIG. 5) for reducing the multipath distortion effects of the channel that the OFDM signal is transmitted through.

[0014] Preliminary frequency-domain tap computation unit 50 computes preliminary frequency-domain equalizer tap values using a training symbol (e.g., a training symbol within training sequence 32 of FIG. 3) stored in a memory 52. A conventional technique for computing a tap value for each subcarrier is to set the tap for a subcarrier equal to the training subsymbol known to be transmitted on the subcarrier (as stored in memory 52) divided by the actual subsymbol output from FFT unit 46 on the subcarrier. The preliminary frequency-domain equalizer tap values are passed to a channel estimate unit 54 that inverts the equalizer tap values to form an estimate of the channel frequency response. (It should be noted that an alternative method for deriving the estimated channel frequency response is to solve for the channel estimate directly by dividing the output of FFT unit 46 by the known training symbol). A more precise channel estimate can be formed by averaging channel estimates over multiple training symbols.

[0015] The channel estimate is passed to an IFFT unit 58 (either directly or via an optional noise reduction unit 56 described in further detail below) that applies an Inverse Fast Fourier Transform such that the frequency-domain channel estimate is transformed into a time-domain channel estimate. The time-domain channel estimate is passed to a peak detector 60 that monitors the output of IFFT unit 58 for a maximum peak in the magnitude of the time-domain channel estimate. Peak detection unit 60 passes the time-domain channel estimate (either directly or via an optional noise reduction unit 64 described in further detail below) to a channel estimate adjustment unit 66. Peak detection unit 60 also outputs an index of a maximum peak within the channel estimate to channel estimate adjustment unit 66 as well as to an FFT window adjustment unit 62. A comparator circuit (not shown) may be used to detect the maximum peak. The comparator circuit monitors the magnitudes of the samples of the channel estimate and outputs the index of the sample having the largest magnitude. The index of the maximum peak corresponds to the strongest path of the OFDM channel (i.e., the OFDM subcarrier having the strongest path) and is compared to the FFT window location. Ideally, with no FFT window offset, the index of the main peak aligns with the beginning of the FFT window since the OFDM receiver is programmed to lock onto the OFDM signal that is from the strongest path. However, when a FFT window offset is

timate unit 54, IFFT unit 58, peak detection unit 60, and noise reduction unit 64, described above, as well as an FFT unit 76 and channel estimate modifier 78 in a feedback loop between noise reduction unit 64 and channel estimate unit 54. In operation, channel estimate unit 54, as discussed above, forms an estimate of the channel frequency response. It should be noted that the channel estimate only represents a subset of the subcarriers carrying the training sequence. More specifically, in the proposed ETSI and IEEE standards only 52 of the 64 subcarriers in the training sequence have non-zero values while the other 12 subcarriers have zero values. Accordingly, when channel estimate unit 54 forms the estimate of the channel frequency response, channel estimate unit 54 sets the value of the 12 subcarriers to a default value (e.g., zero). The default value masks the actual values of the channel estimate for the 12 subcarriers. System 74 is utilized to approximate the masked values of the channel estimate, as discussed in further detail below.

[0023] The channel estimate is passed to IFFT unit 58 which applies an Inverse Fast Fourier Transform such that the frequency-domain channel estimate is transformed into a time-domain channel estimate. The time-domain channel estimate is passed to peak detector 60 which monitors the output of IFFT unit 58 for a maximum peak in the magnitude of the time-domain channel estimate, as discussed above. Peak detection unit 60 passes the time-domain channel estimate, via noise reduction unit 64, to channel estimate adjustment unit 66. Peak detection unit 60 also outputs an index of a maximum peak within the channel estimate to channel estimate adjustment unit 66 as well as to FFT window adjustment unit 62.

[0024] As discussed above, noise reduction unit 64 reduces the additive channel noise contained in the time-domain channel estimate by zeroing out any taps outside of a predetermined range centered around the main channel tap. In system 74, noise reduction unit 64 passes the time-domain channel estimate to channel estimate adjustment unit 66 after the channel estimate is fed back to channel estimate unit 54 a predetermined number of times. More specifically, the time-domain channel estimate is passed to FFT unit 76 which transforms the time-domain channel estimate into a frequency-domain channel estimate. Afterwards, the frequency-domain channel estimate is passed to channel estimate modifier 78 which modifies the channel estimate output from channel estimator 54. More specifically, channel estimate modifier 78 sets the masked subcarriers output from channel estimator 54 equal to the values of the corresponding subcarriers output from FFT unit 76. Channel estimate modifier 78 also sets the non-zero subcarriers (i.e., non-masked subcarriers) of the channel estimate equal to the values originally provided by channel estimator 54. After the recursive feedback occurs a predetermined number of times, noise reduction unit 64 passes the recursively filtered channel estimate to channel estimate adjustment unit 66 which further processes the channel estimate (now including approximations for the masked subcarriers), as described above.

[0025] Thus according to the principle of the present invention, an OFDM receiver extracts a training symbol from a fast Fourier transformed OFDM signal and processes the extracted training symbol to derive an FFT window adjustment factor and an associated equalizer tap initialization value. The OFDM receiver controls the position of an FFT window and the initialization of equalizer taps using the FFT adjustment factor and equalizer tap initialization value. The OFDM receiver preferably filters the fast Fourier transformed OFDM signal to remove additive channel noise and increase the likelihood of reliable equalizer tap initialization in a low SNR environment.

Claims

1. A method of processing an Orthogonal Frequency Division Multiplexed (OFDM) signal in an OFDM receiver, the method **characterized by** the steps of:

   Fast Fourier Transforming (46) a received OFDM signal;
   Extracting (50, 52) a training symbol from the Fast Fourier Transformed OFDM signal;
   Processing (60) the extracted training symbol to derive an FFT window adjustment value and an associated equalizer tap initialization value; and
   Controlling (62) a position of an FFT window and an initialization of an equalizer tap using the FFT window adjustment value and the associated equalizer tap initialization value.

2. The method of claim 1, **characterized in that** the OFDM receiver is implemented in one of a wireless LAN adapter, home networking terminal, a portable terminal, and a desktop terminal.

3. The method of claim 1, **characterized in that** the window adjustment value represents a window drift correction.

4. The method of claim 3, **characterized in that** the equalizer tap initialization value is pre-compensated to negate the effect of the window drift correction on an equalizer tap.

5. The method of claim 1, **characterized in that** the step of processing the extracted training symbol includes the steps of:

   deriving a channel response (54) from the extracted training symbol; and

means for receiving (42) an OFDM signal;
means for applying (44) an FFT window to the received OFDM signal;
means for Fast Fourier Transforming (46) the windowed OFDM signal;
means for equalizing (72) the transformed OFDM signal;
means for detecting (60, 62) a window drift in the application of the FFT window; and
means for adjusting (60, 62) the application of the FFT window to reduce the detected window drift and for adjusting (66) the initialization of the means for equalizing such that the means for equalizing is pre-compensated for the effects of the reduction of the window drift.

20. The apparatus of claim 19, further **characterized by**:

means for reducing noise (56, 64) in the transformed OFDM signal.

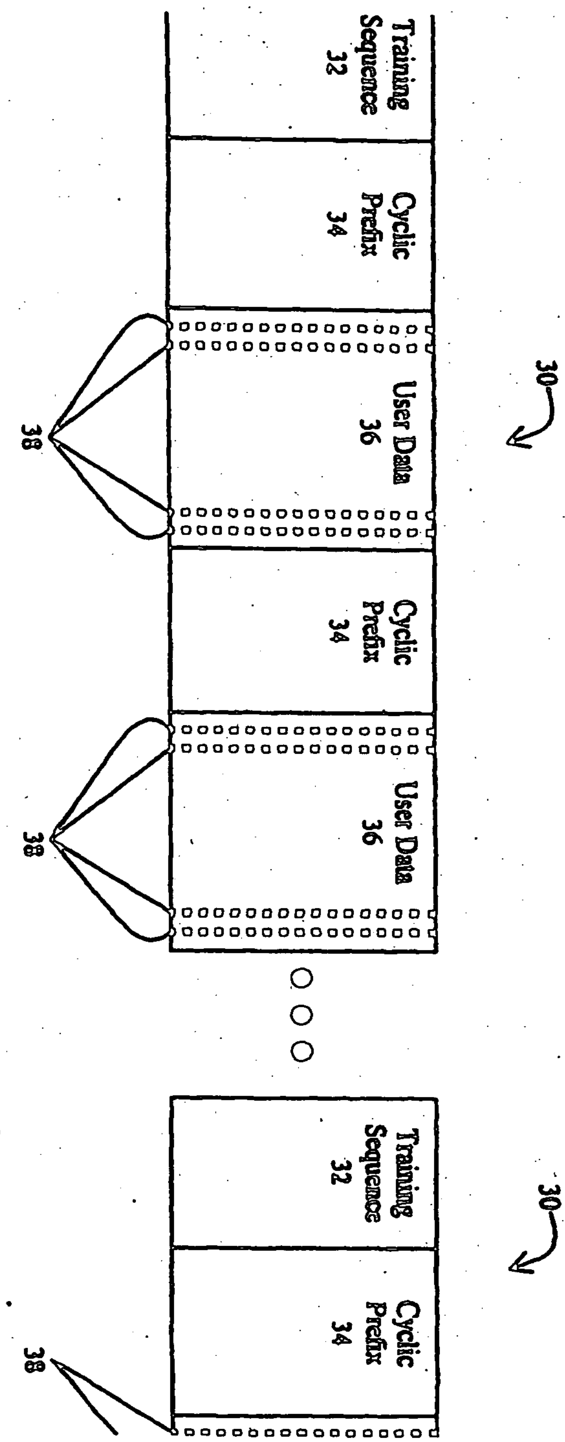
30
Training Sequence 32
Cyclic Prefix 34
User Data 36
38
Cyclic Prefix 34
User Data 36
38
30
Training Sequence 32
Cyclic Prefix 34
38

FIG. 3

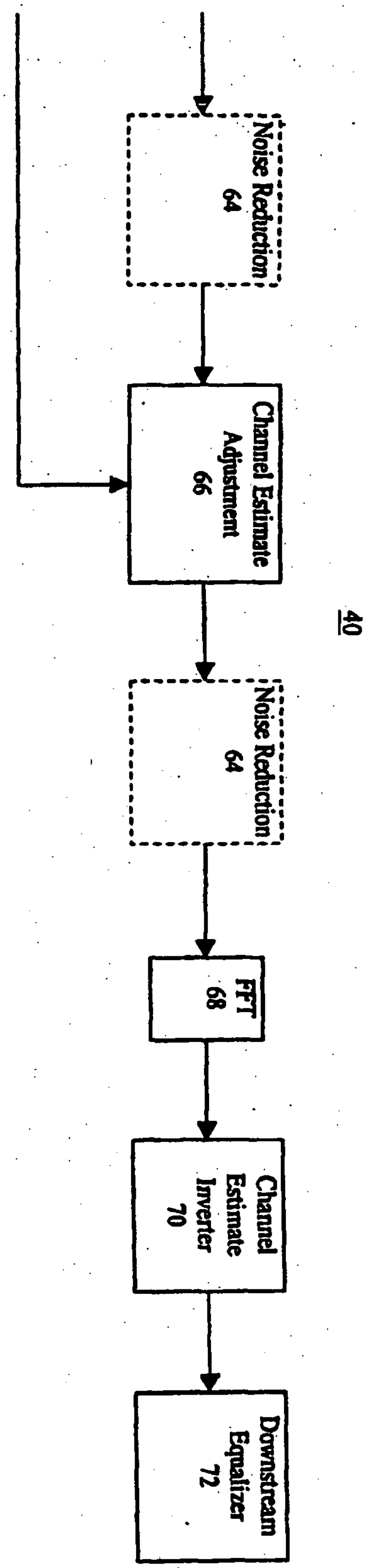
Noise Reduction
64
Channel Estimate
Adjustment
66
40
Noise Reduction
64
FFT
68
Channel
Estimate
Inverter
70
Downstream
Equalizer
72

FIG. 5

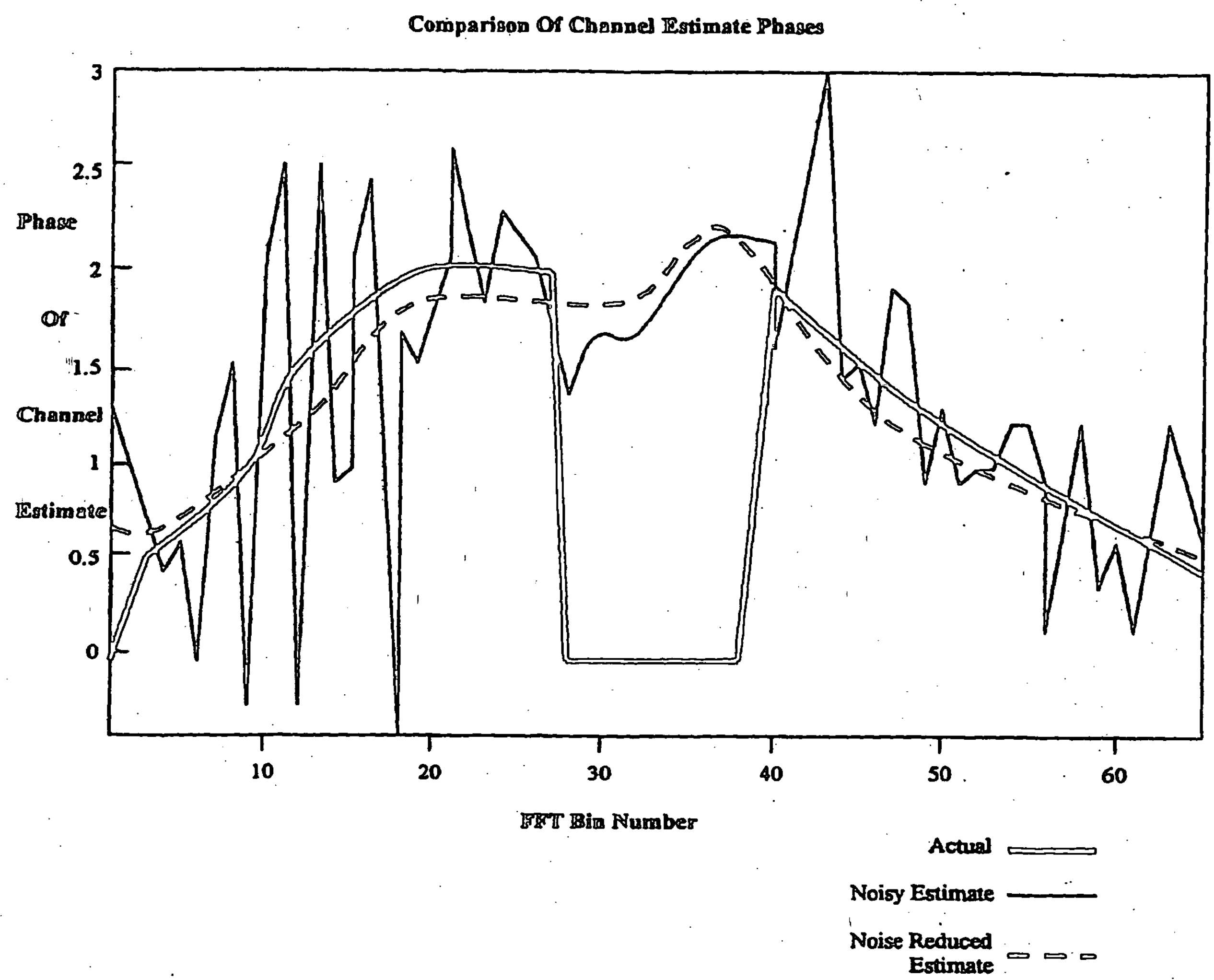
Comparison Of Channel Estimate Phases
3
2.5
2
1.5
1
0.5
0
Phase
Of
Channel
Estimate
10
20
30
40
50
60
FFT Bin Number
Actual
Noisy Estimate
Noise Reduced Estimate

FIG. 7